ISSN 2816-8070

RESEARCH ARTICLE

Enhancing the Credibility of Sustainability Disclosure and Assurance: A Behavioral–Probabilistic Framework and Institutional Market Evidence from an Emerging Economy

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Abstract

Purpose and Design: This study develops and empirically validates a behavioral probabilistic framework to explain how the credibility of sustainability disclosure and assurance affects financial outcomes in banking and capital market institutions. By modeling non-linear cognitive uncertainty and institutional moderation mechanisms, the study provides a behavioral account of why assurance credibility varies across regulatory and market environments. The research integrates theoretical development with comparative empirical evidence from an emerging economy context.

Method and Approach: A mixed method design is employed, combining Structural Equation Modeling (SEM), instrumental variable estimation and probabilistic simulation techniques. The empirical analysis draws on sustainability reports and external assurance statements issued by banks and listed firms over the period 2020–2024. Behavioral constructs capturing cognitive uncertainty, bias and ethical framing are incorporated to assess how decision related interference influences assurance credibility and its financial consequences. Full transparency of measurement instruments, correlation matrices and econometric diagnostics is provided to ensure replicability and independent evaluation.

Findings: Results indicate that higher quality sustainability disclosure significantly enhances assurance credibility, which in turn reduces firms' cost of capital and improves market liquidity. Cognitive uncertainty weakens the disclosure assurance relationship, while governance intensity and banking integration strengthen the financial impact of credible assurance.

Originality/Value: The study reconceptualizes sustainability assurance as a behavioral probabilistic process shaped by cognitive and institutional factors rather than a purely deterministic verification mechanism, thereby extending the behavioral foundations of auditing and ESG reporting in emerging markets.

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***Received Date**: February 12, 2026, **Accepted Date**: March 03, 2026, **Published Date**: April 20, 2026*

***Citation:** Lotfy AEA. Enhancing the Credibility of Sustainability Disclosure and Assurance: A Behavioral–Probabilistic Framework and Institutional Market Evidence from an Emerging Economy. Int J Bank Fin Ins Tech. 2026;4(1):1-44.*

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Theoretical, Practical and Social Implications: The framework advances research at the intersection of sustainability assurance, behavioral auditing and institutional finance. It offers regulators and practitioners structured guidance for strengthening assurance credibility and supports improved transparency, reduced information asymmetry and more sustainable financial decision-making.

Key Words: *Sustainability disclosure; Assurance credibility; Behavioral probabilistic framework; Banking; Capital markets; ESG; Behavioral auditing*

1. Introduction

The accelerating global emphasis on sustainability, responsible finance and digital transformation has substantially reshaped the foundations of accounting, auditing and capital market regulation. Over the past decade, Environmental, Social and Governance (ESG) disclosure has evolved from a largely voluntary narrative instrument into a central component of corporate transparency, risk assessment and valuation mechanisms [1,2]. Despite advances in regulatory initiatives such as the EU Corporate Sustainability Reporting Directive (CSRD) and the International Sustainability Standards Board (ISSB), persistent concerns remain regarding the credibility, comparability and assurance quality of ESG information [3]. Fragmented assurance practices and behavioral biases in managerial reporting continue to undermine the reliability of sustainability disclosures [1,2,4-6].

The accounting and auditing profession are therefore undergoing a structural transition. Investors and financial intermediaries increasingly demand decision useful, independently assured and cognitively robust ESG information that can be integrated into risk-based banking models and market pricing mechanisms. However, conventional assurance models grounded in deterministic audit risk frameworks often struggle to capture the non-linear, contextual and behavioral dimensions of sustainability related judgments [7]. ESG assurance decisions frequently involve ambiguous metrics, forward looking estimates and qualitative assessments that challenge purely linear verification approaches.

These limitations motivate the development of a broader theoretical architecture one that integrates probabilistic reasoning with cognitive decision theory to better explain how assurance credibility emerges under conditions of bounded rationality and institutional complexity [8,9]. Rather than treating assurance as a purely mechanical verification exercise, this perspective conceptualizes it as a behavioral probabilistic process shaped by cognitive uncertainty, ethical framing and institutional incentives.

Accordingly, this study introduces a behavioral probabilistic ESG disclosure and assurance framework, a multidimensional model linking ESG disclosure quality, assurance credibility and financing efficiency within banking and capital market ecosystems. The framework posits that ESG disclosure is not merely a compliance activity but a judgment intensive process influenced by interacting perceptions among managers, auditors, banks and investors. These interactions reflect bounded rationality, probabilistic belief updating and institutional coordination, leading to variation in assurance intensity and market responses.

1.1. Motivation and research gap

Although a substantial body of literature examines ESG reporting quality and its market consequences, most empirical studies emphasize linear associations between disclosure metrics and financial performance [10]. Comparatively fewer studies investigate the behavioral cognitive dynamics underlying ESG assurance decisions or the probabilistic mechanisms through which assurance credibility influences market outcomes particularly in emerging market contexts characterized by institutional asymmetries and evolving regulatory enforcement [7].

Furthermore, the interaction between banks as sustainability-oriented lenders and stock exchanges as disclosure enforcers remains theoretically underdeveloped [10,11]. Existing models rarely integrate institutional coordination and cognitive moderation into a unified explanation of assurance credibility.

In Egypt, as in many emerging economies, regulators such as the Financial Regulatory Authority (FRA) and the Central Bank of Egypt (CBE) have introduced ESG initiatives and green finance guidelines. Nevertheless, these efforts remain partially voluntary, unevenly enforced and inconsistently assured. The S&P/EGX ESG index, while pioneering in its regional context, continues to face challenges in embedding standardized assurance protocols. This environment provides a natural laboratory for examining how a behavioral probabilistic assurance framework may enhance credibility, reduce information asymmetry and support convergence with international benchmarks [12].

1.2. Theoretical foundations the framework builds upon three complementary theoretical pillars

- **Signaling theory:** Firms use ESG disclosure and assurance mechanisms to signal credibility and reduce information asymmetry vis-à-vis lenders and investors [2].
- **Non-classical probabilistic decision theory:** Empirical evidence suggests that economic and audit judgments do not always conform strictly to classical probability axioms. Contextual dependence and belief updating under ambiguity motivate the use of probabilistic modeling approaches that allow for non-linear interactions and cognitive interference effects [8,9,13].
- **Cognitive behavioral theory:** Assurance and disclosure quality are shaped by bounded rationality, heuristic bias, ethical framing and cognitive load affecting preparers and auditors [14,15].

Together, these perspectives support a behavioral probabilistic view of ESG assurance credibility, integrating informational signaling, cognitive moderation and institutional context.

1.3. Research objectives and questions

This study seeks to:

- Develop and empirically validate a behavioral probabilistic model explaining variations in ESG disclosure and assurance quality across banking and capital market contexts.
- Examine how ESG assurance credibility affects cost of capital, credit risk perceptions and market liquidity in Egypt relative to international benchmarks.

- Identify regulatory and institutional adjustments that could strengthen assurance coherence and support structured ESG assurance frameworks for emerging markets.

Accordingly, the study addresses the following questions [5]:

- How do cognitive uncertainty and institutional factors influence ESG assurance credibility?
- To what extent does assure ESG information affect financing efficiency in banks and capital markets?
- What regulatory configurations enhance the credibility and comparability of ESG assurance in emerging economies?

1.4. Methodology and expected contributions

The empirical analysis employs panel data (2020–2024) from Egyptian listed firms and banks, benchmarked against datasets from selected advanced and emerging economies. The study integrates Structural Equation Modeling (SEM), instrumental variable estimation and probabilistic simulation techniques to capture causal interactions among disclosure quality, assurance credibility, cognitive uncertainty and financial performance.

The research contributes to accounting, auditing and sustainable finance literature in four key ways:

1. It develops a behavioral probabilistic framework modeling non-linear and cognitive dimensions of ESG assurance, extending classical audit risk perspectives.
2. It empirically links ESG assurance credibility to financing efficiency and market liquidity, enriching the accounting finance interface.
3. It contextualizes findings within emerging market regulatory ecosystems, highlighting convergence dynamics toward global ESG benchmarks.
4. It offers structured policy implications for strengthening ESG assurance governance, aligning national practices with ISSB, ISAE 3000 and CSRD developments [4,16].

In doing so, the study bridges accounting assurance theory and sustainable finance governance by presenting an empirically grounded and behaviorally informed framework for understanding credibility formation in ESG reporting.

2. Literature Review and Theoretical Development

2.1. ESG disclosure, assurance and sustainable finance research

Sustainability accounting has evolved from a peripheral corporate social responsibility concern into a central determinant of firms' valuation, risk exposure and capital allocation. Since 2020, the convergence of ESG disclosure and external assurance has attracted significant attention in leading accounting and finance journals, as investors increasingly treat verified ESG information as complementary to financial statement reliability [2,5,17]. Despite regulatory progress such as the EU CSRD, the ISSB's IFRS S1/S2 standards and the IFAC IOSCO assurance agenda empirical evidence continues to document heterogeneity in assurance scope, provider independence and enforcement intensity across jurisdictions [4,18-21].

Capital market research indicates that higher-quality ESG reporting reduces information asymmetry and cost of capital [10,22,23]. However, these effects are often conditional upon external assurance. Assurance enhances disclosure credibility in line with signaling theory

and strengthens investor trust [24]. Yet empirical results vary across institutional contexts: in Europe, assurance premiums are reflected in equity pricing, whereas in several emerging markets such effects remain statistically weak [7]. These inconsistencies motivate the development of a unifying framework capable of capturing behavioral and contextual moderators that conventional linear audit risk models do not fully incorporate [25].

2.1.1. From deterministic assurance models to probabilistic cognition: Traditional audit models rely on rational expectations and additive probability structures. Recent behavioral accounting research challenges these assumptions, demonstrating that auditors and managers operate under bounded rationality, cognitive bias and contextual dependence [14,26,27]. Decision outcomes may therefore deviate from strict Bayesian updating and exhibit context sensitive probability patterns [8,9].

Emerging non-classical probabilistic approaches emphasize that judgments under ambiguity are shaped by cognitive interference effects and belief revision dynamics rather than purely deterministic calculations [28]. Within ESG assurance contexts characterized by forward looking estimates and qualitative metrics such probabilistic cognition provides a more flexible explanatory structure than static risk-based models.

2.1.2. ESG assurance in banking and capital market settings: Banks and stock exchanges play pivotal roles in translating ESG information into financing outcomes. Research shows that banks increasingly incorporate ESG ratings into credit risk assessment and loan covenants [11,29]. Stock exchanges, through sustainability indices such as the S&P/EGX ESG index and the NASDAQ ESG leaders index, promote standardized disclosure metrics [30]. Nonetheless, disclosure expansion frequently outpaces assurance quality, generating a "credibility gap" [31]. Auditors face challenges in verifying forward looking environmental data and qualitative social indicators, while banks often rely on partially verified ESG scores in pricing decisions, as shown in Table 1 [32].

Table 1: *Recent developments in ESG disclosure and assurance research (2020–2025).*

Research theme	Representative studies	Main findings	Identified gaps
ESG disclosure quality and market valuation	Anderson et al. [10]	Higher disclosure → lower cost of capital, improved liquidity	Contextual and behavioral moderators not modeled
Assurance credibility and investor trust	Baik et al. [5]	External assurance enhances reliability; assurance type matters	Lack of theoretical integration beyond linear models
Regulatory convergence (EU, US, Asia)	IFAC [4]; OECD [16]; IAASB [18]	Global move toward unified sustainability standards	Absence of behavioral or probabilistic modeling
ESG in banking and capital markets	Wu et al. [11]; UNEPFI [33]	ESG scores affect lending and pricing	Assurance not embedded in credit decisions
Emerging-market evidence (Egypt, Asia, Latam)	Larson [7]	Weak enforcement; fragmented standards	Need for adaptive assurance frameworks

2.1.3. Toward a behavioral probabilistic perspective: Interdisciplinary research suggests that non-classical probabilistic models may better capture human judgment under ambiguity than strictly classical approaches [8,13]. In accounting contexts, these approaches model how conflicting audit evidence, contextual framing and sequential information processing influence belief formation. Cognitive neuroscience research further shows that ESG judgments frequently activate intuitive reasoning under moral and social uncertainty [15].

Accordingly, integrating probabilistic reasoning with cognitive theory enables modeling ESG assurance as a dynamic belief updating process influenced by ethical framing, regulatory signals and stakeholder expectations. This perspective aligns with recent calls for behaviorally informed assurance standards and supports the design of sustainability frameworks that extend beyond compliance toward adaptive learning systems [4,18,34].

2.1.4. Emerging market dynamics: the Egyptian context: Egypt provides a relevant empirical setting for examining these dynamics. The Central Bank of Egypt (CBE) and the Financial Regulatory Authority (FRA) introduced sustainability disclosure guidelines and green finance initiatives between 2019 and 2024, yet enforcement remains partial and assurance largely voluntary. The S&P/EGX ESG index, while regionally innovative, lacks standardized assurance requirements, leading to heterogeneous credibility among listed firms.

This institutional asymmetry reflects patterns observed in other emerging markets, where disclosure expansion exceeds verification capacity [7]. A behavioral probabilistic lens helps explain why similar regulatory initiatives produce divergent market responses across countries.

2.2. Theoretical lenses and model integration (reframed)

2.2.1. Signaling and information economics perspectives: ESG disclosure research is grounded in signaling theory, whereby firms disclose sustainability information to mitigate information asymmetry and reduce perceived risk [2,35,36]. External assurance strengthens signal credibility and lowers cost of capital [22,37,38]. However, signals may be distorted by managerial framing and selective assurance coverage. Greenwashing persists even under disclosure mandates, indicating that investors interpret ESG signals through cognitive heuristics rather than purely Bayesian inference [2,14].

The present framework extends this perspective by incorporating contextual probabilistic updating mechanisms to model how preparers, auditors and investors jointly form uncertain beliefs regarding sustainability performance [8].

2.2.2. Auditing and assurance theory: Classical audit theory conceptualizes assurance quality as a function of independence, evidence sufficiency and risk assessment [5]. Sustainability assurance, however, involves qualitative and forward-looking information that challenges traditional verification boundaries under ISAE 3000 (revised). Recent scholarship expands the assurance expectation gap to include trust, professional judgment, and ethical reasoning [18].

A behavioral probabilistic interpretation views auditor judgment as a process of iterative belief up-dating under uncertainty [9]. Neuroscience research shows that professional skepticism fluctuates with cognitive load and social pressure [15]. Accordingly, ESG

assurance may be conceptualized as a probabilistic cognition system rather than a purely deterministic risk control mechanism [39,40].

2.2.3. Governance and institutional theory: Institutional theory explains ESG assurance diffusion through coercive, normative and mimetic pressures [41]. Convergence toward ISSB, EU CSRD and SEC frameworks depend on enforcement capacity and professional readiness [7,16]. In banking, sustainability risks are increasingly embedded in capital adequacy and disclosure frameworks [42].

Integrating probabilistic cognition with institutional theory clarifies why actors within the same regulatory field may respond heterogeneously: compliance outcomes depend not only on rule design but also on perception, interpretation, and cognitive thresholds, as summarized in Table 2.

Table 2: *Theoretical foundations and key constructs.*

Theory lens	Core assumptions	ESG assurance implications	Integration within behavioral probabilistic framework
Signaling theory [2]	Firms send costly credible signals to investors	External assurance enhances ESG credibility	Models' heterogeneous interpretation of signals under uncertainty
Audit risk model [5]	Assurance quality=f(evidence × independence × risk assessment)	Sustainability metrics introduce non-quantifiable risks	Allows dynamic risk weighting under probabilistic uncertainty
Cognitive behavioral theory [14]	Judgments subject to heuristics, bounded rationality	Auditor cognition affects disclosure and assurance depth	Captures cognitive interference and belief updating
Institutional theory [7]	Rules diffuse through coercive & normative pressures	ESG adoption varies by enforcement strength	Explains heterogeneous compliance probabilities
Non-classical probabilistic decision theory [8,9]	Context influences probability assessments	ESG assurance outcomes are non-linear and contextual	Provides probabilistic modeling basis

2.2.4. Behavioral probabilistic integration in ESG assurance: Recent developments in behavioral decision research highlight that judgment under ambiguity frequently departs from strictly linear and fully rational probability updating. Rather than assuming fixed probability distributions, contemporary probabilistic models recognize that belief revision may be context dependent path sensitive and influenced by evaluative framing. Studies in non-classical decision modeling demonstrate how contextual interactions can generate systematic deviations from classical Bayesian expectations without implying physical behavioral probabilistic processes [8,9,13].

In ESG assurance settings, auditor evaluation functions as an interactive assessment process. Inquiry, clarification requests and materiality discussions may influence managerial disclosure adjustments, creating iterative feedback between preparers and assurers. This

dynamic is consistent with behavioral belief updating mechanisms rather than static verification models.

Recent advances in probabilistic modeling and behavioral auditing research suggest that context sensitive decision structures may better capture audit judgment variability than strictly linear specifications. Rather than assuming fully rational Bayesian updating, emerging work emphasizes bounded rationality, contextual belief revision and non-linear interaction effects in assurance settings. These developments align with broader decision theory contributions and recent behavioral auditing research highlighting judgment dispersion under ambiguity [8,13].

Behavioral accounting experiments further indicate that moral salience and ethical framing affect evaluative thresholds. Evidence from shows that exposure to ethically charged cues can asymmetrically adjust materiality judgments, reflecting bounded rationality and non-linear probability weighting [15]. Such findings support modeling ESG assurance credibility as influenced by both cognitive dispersion and institutional context.

Accordingly, ESG Assurance Credibility (ASC) is conceptualized as:
ASC=f(QP, CB, GI)
where:
QP=Probabilistic uncertainty parameter capturing non-linear judgment dispersion under ambiguity;
CB=Cognitive Bias intensity influencing evaluative weighting;
GI=Governance Institutional strength shaping enforcement coordination and disclosure incentives.

This formulation explains cross market variation in assurance outcomes by integrating behavioral decision variability with institutional governance conditions, while remaining grounded in established decision science and accounting research.

2.2.5. Emerging model synthesis: By integrating these theoretical lenses, the behavioral probabilistic cognitive ESG disclosure and assurance framework establishes a multilevel causal logic:

1. At the micro level, auditors' and managers' cognitive interferences shape assurance intensity.
2. At the meso level, institutional entanglement among banks, regulators and stock exchanges determines assurance diffusion.
3. At the macro level, verified ESG disclosures influence capital market efficiency and systemic trust.

2.3. Empirical gaps and hypothesis development (revised–safe framing)

2.3.1. Empirical gaps in ESG disclosure and assurance: Despite the rapid expansion of ESG disclosure research during the past five years, significant empirical fragmentation persists. Most empirical models estimate linear associations between ESG ratings and financial performance using regression-based frameworks [10,43]. Such approaches often understate the interactive roles of cognition, institutional design and probabilistic uncertainty in shaping assurance outcomes. Recent meta-analyses report substantial variation in assurance effects across industries, provider types and levels of market maturity [44].

A disciplinary disconnect also remains between accounting research emphasizing measurement reliability and finance research focusing on market pricing of ESG information [22]. Auditing scholarship has rarely incorporated behavioral constructs such as ethical framing, affective trust and cognitive load into econometric ESG models [15].

Consequently, the call for conceptually grounded mechanisms consistent with recent calls for stronger conceptual integration in ESG research. It remains insufficiently addressed in this domain.

A second gap concerns banking intermediation. Although regulators increasingly embed green finance requirements within Basel III pillar 3 frameworks, limited empirical evidence examines how assured ESG information influences credit pricing, loan spreads and collateral valuation [42].

Similarly, the assurance dimension of stock market ESG indices such as S&P/EGX ESG or NASDAQ ESG leaders remains underexplored [30]. Many indices rely on self-reported ESG metrics rather than independently verified data, generating informational noise [2].

A third gap relates to emerging-market institutional asymmetry. Empirical evidence from Egypt, India and Brazil reveals weak statistical associations between ESG assurance and firm performance, frequently attributed to regulatory inertia and limited assurance expertise [7]. These findings justify adopting a behavioral probabilistic lens that conceptualizes assurance credibility as an outcome shaped by cognitive uncertainty and institutional variation rather than purely deterministic risk factors, as summarized in Table 3 [8].

2.3.2. Formulation of hypotheses: Building on the preceding theoretical synthesis, the following hypotheses guide the empirical analysis:

- **H1 (Disclosure assurance link):** Firms providing externally assured ESG disclosures exhibit lower information asymmetry and reduced cost of capital compared with unassured firms.
- **H2 (Cognitive moderation):** Auditor cognitive interference proxied by workload, ethical framing or decision time moderates the relationship between ESG disclosure complexity and assurance credibility [45].
- **H3 (Banking integration effect):** Banks that embed ESG metrics in lending decisions amplify the positive association between assurance credibility and financing efficiency [46].
- **H4 (Institutional coordination):** The degree of coordination between regulators, exchanges and professional bodies strengthens cross market consistency in assurance practices [47].
- **H5 (Behavioral probabilistic adjustment effect):** Behavioral probabilistic parameters capturing cognitive uncertainty and information complexity explain residual variance in ESG assurance outcomes beyond conventional audit risk variables.

These hypotheses are empirically tested using structural equation modeling and probabilistic estimation techniques consistent with contextual decision frameworks.

Table 3: *Empirical gaps and research propositions.*

Empirical gap	Evidence from prior studies (2020–2025)	Behavioral probabilistic interpretation	Research Proposition (RP)
Limited integration of cognition in ESG assurance models	Loewenstein et al. [15]	Assurance judgments influenced by cognitive interference and bounded rationality	P1: Auditor cognitive load moderates the relationship between ESG disclosure complexity and assurance quality.
Weak connection between assured ESG data and financing outcomes	Dodgson et al. [12]; BIS [42]	Uncertainty in bank risk-pricing reduces consistent transmission of assurance signals	P2: Assured ESG disclosures reduce firms' cost of capital more strongly when banks integrate ESG metrics into lending models.
Lack of cross-institutional diffusion mechanisms	OECD [16]	Institutional coordination affects probability of regulatory convergence	P3: Institutional coordination intensity positively influences cross-market convergence of ESG assurance standards.
Inconsistent assurance premiums in emerging markets	Larson [7]; Anderson et al. [10]	Variance driven by information asymmetry and heterogeneous interpretation	P4: Behavioral–probabilistic adjustments explain cross-country variance in ESG assurance premiums.
Insufficient theoretical link between ESG assurance and audit economics	Baik et al. [5]	Non-linear feedback between assurance credibility and audit-fee sensitivity	P5: ESG assurance credibility mediates the effect of assurance provider type on audit-fee sensitivity.

2.3.3. Conceptual model and expected contributions: This section conceptualizes the behavioral probabilistic ESG disclosure and assurance framework as a multilevel system:

- **Input layer:** ESG disclosure quality, assurance type, auditor independence.
- **Cognitive layer:** Probabilistic variables capturing judgment interference and bounded rationality effects.
- **Institutional layer:** Banking incentives, regulatory coordination and market maturity.
- **Outcome layer:** Cost of capital, market liquidity and investor trust.

The model integrates micro level decision behavior with macro-level financial governance outcomes, thereby addressing causal pathways between accounting information and capital market consequences.

Expected contributions include:

- Extending audit risk theory through a behavioral probabilistic perspective on assurance judgments [8].
- Linking ESG assurance credibility to banking and capital market performance, strengthening the accounting finance interface [22].

- Developing measurable constructs Assurance Credibility (ASC), Cognitive Interference (CI) and Institutional Coordination (IC) to operationalize emerging governance mechanisms for empirical testing.
- Providing structured policy implications supporting convergence with ISSB and IAASB initiatives [5,18].

Collectively, these contributions address the gap between deterministic assurance models and behaviorally informed governance frameworks while maintaining empirical testability and institutional relevance.

3. Conceptual Framework for Enhanced ESG Assurance Transparency

3.1. Conceptual overview

This framework is not proposed as a regulatory standard nor as a replacement for existing IAASB or ISSB initiatives. Rather, it is intended as an analytical model designed to facilitate empirical testing and conceptual clarification within academic research.

Recent developments in sustainability accounting indicate that ESG disclosure and assurance operate within an increasingly complex environment characterized by interdependence, ambiguity and decision relevant uncertainty. Conventional frameworks grounded in linear cause effect relationships may not fully capture the behavioral and informational features embedded in sustainability reporting, particularly when disclosures include forward looking estimates and narrative claims. To address these limitations, this chapter develops the ESG disclosure and assurance framework (Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)) a comprehensive system integrating accounting assurance theory, behavioral decision models and non-classical probabilistic reasoning to explain how credible ESG information is generated, assured and transmitted through financial markets [48].

The Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) is grounded in the assumption that key decision makers managers, auditors and investors do not always behave as fully rational agents. Their perceptions, ethical framing and bounded cognition influence disclosure choices, assurance judgments and credibility formation. These behavioral patterns are modeled through probabilistic belief updating mechanisms reflecting bounded rationality and context dependent evaluation processes [8,13,49].

Within this architecture, ESG information passes through four interrelated subsystems:

- **Disclosure System (DS):** Firms prepare ESG reports reflecting environmental, social and governance metrics.
- **Assurance System (AS):** Independent auditors or third parties verify and evaluate the disclosed information.
- **Cognitive Behavioral System (CBS):** Decision agents process sustainability information un-der ambiguity, cognitive constraints and ethical framing.
- **Institutional Financial System (IFS):** Banks and capital markets internalize assured ESG in-formation into pricing, lending and investment processes.

This sequence forms a closed informational loop, in which credible assurance strengthens market trust, improved liquidity reinforces incentives for disclosure and enhanced transparency reduces uncertainty supporting a self-adjusting sustainable finance ecosystem [2,5].

The framework therefore links micro level accounting judgments to macro level capital market outcomes through theoretically consistent and empirically testable mechanisms.

3.2. Framework components and constructs

The Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) decomposes into four subsystems comprising twelve core constructs. Each construct is measurable and grounded in established theoretical foundations from accounting, auditing, cognitive science and non-classical decision modeling [10,15,50,51], as shown in Table 4.

3.2.1. Disclosure System (DS): The disclosure system governs how firms communicate sustainability information. Its main construct ESG Disclosure Quality (ESGDQ) captures the scope, depth and reliability of reported ESG metrics. ESGDQ is shaped by internal governance intensity, industry materiality and external pressures from exchanges and investors. Disclosure volume alone is insufficient; credibility depends on verification and assurance conditions that shape investor interpretation.

Table 4: *Core components and constructs of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF).*

Subsystem	Core constructs	Definition	Primary theoretical basis	Expected outcome
Disclosure System (DS)	ESGDQ	Quality, scope, and depth of sustainability information disclosed by firms	Signaling theory	Enhanced transparency and investor confidence
Assurance System (AS)	ASC, APT, ASS	Credibility, provider type, and scope of ESG assurance	Audit & assurance theory	Improved information reliability
Cognitive Behavioral System (CBS)	QP, CB, EF, CL	Probabilistic uncertainty, cognitive biases, ethical framing, and cognitive load influencing judgment	Non-classical decision & behavioral theory	Reduced judgment error and improved interpretability
Institutional–Financial System (IFS)	GI, BI, ML, CC	Governance enforcement, bank ESG integration, market liquidity, and cost of capital	Institutional & financial theories	Financing efficiency and systemic trust

3.2.2. Assurance System (AS): The Assurance System establishes credibility through independent verification and includes:

- **Assurance Credibility (ASC):** Perceived reliability of verified ESG information [5].
- **Assurance Provider Type (APT):** Whether assurance is provided by a Big4 firm, specialist, or internal auditor.
- **Assurance Scope (AS):** Coverage breadth limited or reasonable affecting assurance depth and investor confidence [18].

These constructs represent the supply-side foundations of trust in sustainability reporting.

3.2.3. Cognitive Behavioral System (CBS): The CBS captures decision agents' behavioral mechanisms shaping assurance judgments:

- **QP (Probabilistic Uncertainty Index):** Degree of decision uncertainty and contextual dependence in assurance judgments, reflecting belief dispersion under ambiguity [8,14].
- **Cognitive Bias (CB):** Deviations from normative judgment due to heuristics, framing, or workload [14].
- **Ethical Framing (EF):** The extent to which moral priming shapes professional skepticism and evaluation thresholds [15].
- **Cognitive Load (CL):** Information processing constraint affecting assurance precision [15].

Together, these constructs explain heterogeneity in assurance decisions under ambiguity and align with non-classical decision frameworks emphasizing context-sensitive belief updating [13].

3.2.4. Institutional Financial System (IFS): The IFS connect assured ESG information to market and financing outcomes:

- **Governance Intensity (GI):** Regulatory strength and enforcement capacity influencing assurance adoption [16].
- **Bank Integration (BI):** Extent to which banks embed ESG metrics into credit and risk models [42].
- **Market Liquidity (ML):** Capital market responsiveness to verified sustainability information [10].
- **Cost of Capital (CC):** financing efficiency arising from reduced uncertainty and reputational risk [2].

This subsystem operationalizes the pathway from assurance credibility to measurable financial out-comes.

The four subsystems interact dynamically: higher quality disclosure increases engagement with assurance; assurance credibility influences cognitive uncertainty and verified information affects market pricing and financing mechanisms. This feedback structure reflects cross-actor interdependence in which managerial, auditor, and investor interpretations influence one another over time. By formalizing these relations, the framework extends ESG assurance modeling beyond deterministic linear designs toward adaptive, behaviorally informed architectures that remain conceptually coherent and empirically observable.

3.3. Mathematical formulation

To operationalize the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF), five structural equations describe sequential and recursive relations among disclosure, assurance, cognition and financial outcomes [8]. Following analytical modeling conventions [2,5,13], each equation represents a theoretically derived pathway, as summarized in Table 5. The structural relationships formalized in equations (1)–(5) correspond directly to hypotheses H1–H5 developed in section 2.3. Rather than restating the hypotheses, this section translates them into analytical specifications suitable for empirical estimation.

Table 5: *Analytical equations and expected coefficient signs.*

Eq. no.	Dependent variable	Key predictors	Expected sign	Theoretical basis
1	ASC	ESGDQ, APT, ASS	+	Signaling & audit theory
2	QP	CB, EF, CL	+/−	Cognitive behavioral theory
3	ASC*	ASC, QP	+ (Nonlinear)	Non-classical decision modeling
4	CC	ASC*, GI, BI	−	Financial governance model
5	ML	ASC*, ESGDQ, GI, BI	+	Market microstructure theory

3.3.1. Disclosure assurance equation:

ASCi=α0+α1ESGDQi+α2APTi+α3ASSi+εiASC_i=\alpha_0+\alpha_1ESGDQ_i+\alpha_2APT_i+\alpha_3ASS_i+\varepsilon_iASCi=α0+α1ESGDQi+α2APTi+α3ASSi+εi (1)

where,
ASCiASC_iASCi represents assurance credibility for firm iii,
ESGDQiESGDQ_iESGDQi is disclosure quality,
APTiAPT_iAPTi is provider type (Big 4=1), and
ASSiASS_iASSi is assurance scope.

Expected signs: α1>0, α2>0, α3>0\alpha_1>0,\;\alpha_2>0,\;\alpha_3>0α1>0,α2>0,α3>0. This captures the signaling mechanism through which higher-quality disclosure is associated with stronger assurance credibility.

3.3.2. Cognitive adjustment equation:

QPi=β0+β1CBi+β2EFi+β3CLi+uiQP_i=\beta_0+\beta_1CB_i+\beta_2EF_i+\beta_3CL_i+u_iQPi=β0+β1CBi+β2EFi+β3CLi+ui (2)

QPiQP_iQPi is a probabilistic uncertainty index reflecting contextual ambiguity in assurance judgments;
CBiCB_iCBi, EFiEF_iEFi, and
CLiCL_iCLi denote cognitive bias, ethical framing and cognitive load.

Expected signs: β1,β3>0\beta_1,\beta_3>0β1,β3>0 (greater bias/load increases uncertainty), while β2<0\beta_2<0β2<0 (ethical framing reduces uncertainty) [15].

3.3.3. Behavioral probabilistic assurance adjustment function:

ASCi∗=ASCi(1−e−QPi)ASC^*_i=ASC_i\left(1-e^{-QP_i}\right)ASCi∗=ASCi(1−e−QPi) (3)

ASCi∗ASC^*_iASCi∗ denotes assurance credibility adjusted for probabilistic uncertainty effects. The exponential term captures diminishing marginal adjustment as uncertainty increases: when QP→0QP\to 0QP→0, adjustment is minimal; as QPQPQP rises, the adjusted credibility approaches the baseline ASCASCASC. This non-linear transformation is consistent with bounded rational judgment under ambiguity [8,13].

3.3.4. Financing efficiency equation:

CCi=γ0−γ1ASCi∗+γ2GIi+γ3BIi+ηiCC_i=\gamma_0-\gamma_1ASC^*_i+\gamma_2GI_i+\gamma_3BI_i+\eta_iCCi=γ0−γ1ASCi∗+γ2GIi+γ3BIi+ηi (4)

CCiCC_iCCi is cost of capital;
GIiGI_iGIi is governance intensity;
BIiBI_iBIi is bank integration.

Expected signs: γ1<0, γ2<0, γ3<0\gamma_1<0,\;\gamma_2<0,\;\gamma_3<0γ1<0,γ2<0,γ3<0. Stronger assurance credibility and institutional enforcement reduce financing costs [10].

3.3.5. Market liquidity equation:

MLi=δ0+δ1ASCi∗+δ2ESGDQi+δ3GIi+δ4BIi+ξiML_i=\delta_0+\delta_1ASC^*_i+\delta_2ESGDQ_i+\delta_3GI_i+\delta_4BI_i+\xi_iMLi=δ0+δ1ASCi∗+δ2ESGDQi+δ3GIi+δ4BIi+ξi (5)

MLiML_iMLi denotes market liquidity. Positive coefficients indicate that credible assurance and richer disclosure improve liquidity through enhanced transparency and reduced perceived information risk [2].

These equations jointly satisfy internal coherence and empirical testability and can be estimated using SEM and probabilistic simulation approaches.

3.4. Dynamic interactions and adaptive processes

Beyond static equations, the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) operates as an adaptive information system in which actors' judgments and institutional incentives coevolve, as shown in Table 6.

3.4.1. Iterative feedback and adaptive updating: Auditors and managers exchange iterative signals through cycles of disclosure revision, assurance inquiry and narrative refinement. Each iteration may reshape evaluation thresholds and credibility assessments through context dependent updating [8]. When assurance credibility rises, investor confidence increases, reinforcing incentives for improved disclosure quality and generating positive feedback. Conversely, cognitive overload or weak ethical framing may reduce assurance precision and weaken the credibility channel [14].

3.4.2. Institutional interdependence and coordination: Banks, regulators, and exchanges exhibit cross system coupling: policy changes in one institution may alter expectations and verification priorities in others [16,42,52]. For instance, when a central bank integrates ESG risk into credit scoring, auditors may increase attention to sustainability metrics and firms may expand disclosure scope, supporting cross system coherence in assurance practices [12].

3.4.3. Market response and performativity: Market evaluation of ESG information can influence reporting incentives. Once investors respond to ESG disclosures and assurance signals, firms may adjust reporting strategies, and assurance practices may adapt accordingly. In this sense, ESG assurance is not only diagnostic but also performative: it can help create

and reinforce the trust it seeks to validate, consistent with behaviorally informed decision perspectives [2,13].

Table 6: *Dynamic interaction pathways across subsystems.*

From subsystem	To subsystem	Interaction mechanism	Behavioral probabilistic effect	Empirical indicator
Disclosure system	Assurance system	Report → Verification → Feedback	Competing credibility interpretations under ambiguity	Change in ASC
Assurance system	Cognitive system	Audit judgment → Perception update	Interaction of bias, evidence, and uncertainty	QP variance
Cognitive system	Financial system	Trust transmission into pricing	Belief updating reflected in market expectations	Δ Cost of Capital
Financial system	Disclosure system	Liquidity feedback → Disclosure incentive	Reinforcing loop under institutional incentives	Δ ESGDQ
Regulatory nodes	All subsystems	Policy signals and Framework adoption	Cross-system alignment and convergence	Convergence index of ESG Frameworks

These pathways highlight how ESG assurance functions as an adaptive circuit rather than a purely linear reporting chain.

3.5. Theoretical and practical implications

3.5.1. Theoretical novelty: The Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) provides a behavioral probabilistic extension to classical audit risk and signaling frameworks. It integrates probabilistic decision modeling to capture contextual uncertainty and embeds cognitive behavioral parameters to represent bounded rationality in assurance judgments. This approach aligns with the criterion of conceptual rigor combined with empirical tractability. By integrating disclosure, assurance, cognition and finance, the framework helps unify previously segmented literatures [5].

3.5.2. Empirical observability: Each construct is measurable using existing data sources.

- ESGDQ from sustainability reports (e.g., Refinitiv/Bloomberg ESG metrics).
- ASC and ASS from assurance statements.
- QP from survey based cognitive interference indices.
- CC and ML from market databases.

The framework permits estimation via SEM and probabilistic simulation techniques, enabling fit assessment consistent with empirical-modeling Frameworks.

3.5.3. Policy and practice implications: For regulators, the framework offers a basis for structured ESG assurance governance, clarifying how disclosure credibility and assurance depth interact under uncertainty and institutional variation. For audit firms, it emphasizes the value of integrating behavioral analytics into assurance planning. For banks and investors, it supports ESG linked financing aligned with risk assessment under uncertainty [2,16,42].

4. Research Methodology and Comparative Global Benchmarking

4.1. Research design and comparative context

This study employs a comparative, multi-country mixed method design to empirically validate the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) introduced in chapter 3. Following emphasis on replicable and theory driven design, the methodology integrates quantitative modeling with contextual benchmarking across Egypt, three emerging economies (India, Brazil, South Africa) and two advanced economies (United Kingdom and United States). The comparative configuration enables assessment of how variations in institutional maturity, regulatory enforcement and cognitive behavior affect ESG assurance credibility and financial outcomes [2,5,53]. The research adopts a cross-sectional panel structure covering fiscal years 2020–2024 the period of accelerated convergence under the ISSB's IFRS S1/S2, the EU CSRD and the IAASB sustainability assurance framework. Egypt is positioned as the focal emerging market reference because of its Financial Regulatory Authority (FRA) and Central Bank of Egypt (CBE) sustainability directives. Benchmark economies were selected on three criteria: (1) Comparable capital market size relative to GDP, (2) Adoption stage of ESG reporting standards, and (3) Availability of verifiable assurance statements [4,32,54-56].

The study's design follows the "comparative empirical logic" advocated in building parsimonious, theoretically grounded models capable of identifying systematic differences across institutional contexts rather than idiosyncratic case narratives [5]. The Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) constructs—Disclosure System (DS), Assurance System (AS), Cognitive Behavioral System (CBS) and Institutional Financial System (IFS) are operationalized into measurable variables. The analytical objective is twofold [7]:

- To estimate causal linkages between ESG disclosure, assurance credibility and financial efficiency.
- To benchmark these linkages across heterogeneous institutional environments.

The comparative approach enables inference on how probabilistic cognitive mechanisms interact with differing governance infrastructures, clarifying whether assurance credibility functions as a universal or context-specific signal in capital markets [4,7].

4.2. Data sources, sampling, and variable measurement

4.2.1. Sampling strategy: The sample includes 300 listed entities drawn proportionally from the six economies.

- Egypt (n=60)–Firms listed on the EGX ESG index and major banks;
- India (n=50)–National Stock Exchange (NSE) sustainability disclosers;
- Brazil (n=50)–Brasil Bolsa Balcão (B3) firms reporting under GRI/IFRS S2;
- South Africa (n=40)–JSE integrated reporting leaders;
- United Kingdom (n=50)–FTSE 350 firms subject to FRC guidance;
- United States (n=50)–NYSE/NASDAQ issuers subject to SEC proposed ESG rules.

This composition ensures balance between emerging and advanced jurisdictions while controlling for sectoral heterogeneity through matched industry sampling (financials, energy, manufacturing and services). Firms lacking two consecutive years of ESG assurance data were

excluded to mitigate survivorship and disclosure biases.

The survey was distributed to 124 senior auditors across six jurisdictions. A total of 87 usable responses were obtained (response rate=70.2%). Respondents had an average professional experience of 11.4 years. 62% were partners or senior managers; 38% were ESG specialized assurance leaders (Table 7).

Table 7: *Sample distribution and variable measurement.*

Construct /Symbol	Operational definition/proxy	Source and measurement method	Scale/Expected direction
ESGDQ	ESG Disclosure Quality (ESGDQ)=weighted index of scope × depth × reliability	Refinitiv ESG; textual scoring of GRI/ISSB alignment	Continuous (0–1); ↑ better quality
ASC	Assurance Credibility=existence and depth of external assurance	Audit statements under ISAE 3000 (Revised)	Binary (0/1) and ordinal (1–3)
APT	Assurance Provider Type (APT) (Big 4=3; specialist=2; internal=1)	Annual reports and audit annexes	Ordinal (+ effect on credibility)
ASS	Assurance Scope (ASS) (Limited=1; reasonable=2)	Same as above	Ordinal (+effect on ASC)
QP	Probabilistic (QP) uncertainty index=variance of assurance judgment uncertainty	Survey of audit teams; normalized score	Continuous (0–1); ↑ uncertainty
CB	Cognitive Bias (CB) intensity=heuristic error count per decision set	Experimental audit judgment data	Continuous; ↑ reduces ASC*
EF	Ethical Framing (EF)=moral salience score from linguistic analysis	Text analysis of assurance reports	Continuous; ↑ reduces QP
GI	Governance Intensity (GI)=composite of regulatory enforcement and rule adoption	FRA, CBE, FRC, SEC data; scaled 0–100	Continuous; ↑ reduces CC
BI	Bank Integration (BI)=proportion of green lending and ESG risk weighting	Central banks and BIS green finance data	% of portfolio; ↑ reduces CC
ML	Market Liquidity (ML)=turnover ratio × price impact inverse	Exchange statistics	Continuous; ↑ improves efficiency
CC	Cost of Capital (CC)=Weighted Average Cost (WAC) adjusted for ESG risk	Bloomberg eikon	Continuous; ↓ better performance

4.2.2. Data sources: Data were compiled from.

• Refinitiv ESG and bloomberg terminals quantitative ESG disclosure metrics.
• Corporate annual reports and stand-alone sustainability reports (2020–2024) for textual coding of ESG Disclosure Quality (ESGDQ) and assurance characteristics (ASC, APT, ASS).
• Audit assurance statements issued under ISAE 3000 (revised) and national equivalents to identify provider type and assurance scope [18].

• Capital market and banking datasets for governance, liquidity, and cost-of-capital variables (GI, ML, CC, BI) [29].

Triangulation across multiple sources minimizes measurement error and enhances construct validity [4,57-61].

4.2.3. Detailed construct operationalization: To ensure full construct transparency, this section provides detailed operational definitions, survey items, archival computations, and validation diagnostics for all latent variables (QP, CB, EF and CL).

Cognitive constructs (QP, CB, EF) were measured using structured survey instruments administered to senior auditors engaged in ESG assurance assignments. Credibility Level (CL) was operationalized as a composite index derived from both survey-based perception scores and archival assurance-depth indicators extracted via content analysis [62].

4.2.4. Variable measurement, cognitive constructs (QP, CB, EF) and operationalization: All constructs defined in chapter 3 are translated into empirical proxies consistent with replicability requirements. Quantitative indices are standardized (Z-scores) to ensure cross country comparability. Qualitative constructs (e.g., assurance scope, cognitive bias indicators) are content-analyzed through independent coding of report narratives.

- **Probabilistic Uncertainty (QP):** QP captures perceived ambiguity and judgmental dispersion in ESG assurance engagements. It was measured using six Likert scale items (1–5). The items were:
  QP1: Sustainability disclosures contain forward looking elements difficult to objectively verify.
  QP2: ESG metrics involve interpretive ambiguity during assurance evaluation.
  QP3: Determining materiality thresholds in sustainability assurance requires subjective judgment.
  QP4: Conflicting non-financial evidence complicates assurance conclusions.
  QP5: ESG related risk exposure is harder to quantify than financial risk exposure.
  QP6: Sustainability assurance judgments are highly context dependent.
  Cronbach's α=0.86
  Composite Reliability=0.88
  AVE=0.58

- **Cognitive Bias (CB**): CB was operationalized through a five-item scale adapted from behavioral auditing literature, capturing heuristic reliance, anchoring tendencies and confirmation bias in ESG related judgment contexts.

  CB measures heuristic reliance and bias activation during ESG assurance evaluation. Five items were used:
  CB1: Prior client reputation influences ESG evaluation.
  CB2: Previously used benchmarks affect sustainability metric assessments.
  CB3: Initial impressions shape subsequent evidence interpretation.
  CB4: Time pressure increases reliance on simplified heuristics.
  CB5: Confirmatory information is sometimes weighted more heavily.
  Cronbach's α=0.83
  CR=0.85
  AVE=0.56

- **Ethical Framing (EF):** EF was measured via linguistic content analysis of assurance reports and through survey based moral salience indicators reflecting professional skepticism under ESG related ethical cues. Cronbach's alpha values exceeded 0.83 for all multi-item constructs. Confirmatory factor loadings ranged between 0.71 and 0.88, with Average Variance Extracted (AVE) above 0.55. Table 8 presents confirmatory factor analysis results.

  EF reflects moral salience and professional skepticism activation in ESG engagements. It was measured through three items:
  EF1: Sustainability issues heighten professional responsibility.
  EF2: Ethical considerations influence ESG materiality assessments.
  EF3: ESG disclosures trigger stronger skepticism compared to financial reporting.
  Cronbach's α=0.87
  CR=0.89
  AVE=0.60

- **Credibility Level (CL):** CL was operationalized as a composite index combining:
  (1) Survey based perceived assurance credibility score (3-item scale; α=0.84).
  (2) Archival assurance depth score derived from content analysis (0–3 ordinal scale).

  The composite was computed as:
  CL = 0.6 × Survey_Credibility+0.4 × Assurance_Depth

  Weights were determined using standardized factor loadings from CFA. The composite was normalized between 0 and 1.

Table 8: *Confirmatory factor analysis results*.

Construct	Item	Loading	Cross-loading (max)
QP	QP1	0.81	0.22
QP	QP2	0.84	0.19
QP	QP3	0.76	0.18
QP	QP4	0.79	0.21
QP	QP5	0.72	0.17
QP	QP6	0.83	0.23
CB	CB1	0.74	0.24
CB	CB2	0.77	0.2
CB	CB3	0.82	0.18
CB	CB4	0.75	0.19
CB	CB5	0.79	0.22
EF	EF1	0.86	0.17
EF	EF2	0.88	0.16
EF	EF3	0.84	0.19

Model fit:
CFI=0.958
TLI=0.947
RMSEA=0.051
SRMR=0.043

All factor loadings significant at $p<0.01$.

4.2.5. Data treatment and normalization: All financial data are converted to US dollar equivalents and inflation adjusted using IMF CPI indices. ESGDQ and ASC values are normalized via minmax scaling; cognitive parameters (QP, CB, EF) are standardized to zero mean and unit variance. Missing values (<5%) are imputed using country specific medians. To address potential cross country heteroskedasticity, standard errors are clustered by country and industry [43].

4.2.6. Construct reliability and measurement validity: Reliability of multi-item indices (ESGDQ, QP, CB) is verified through Cronbach's $\alpha>0.80$; confirmatory factor analysis validates convergent and discriminant properties (average variance extracted>0.50). Inter-rater reliability of content coding (assurance statements) exceeds $\kappa=0.82$, satisfying transparency guidelines.

4.2.7. Transparency of measurement and replicability: To enhance methodological transparency and address replicability standards, this study provides full disclosure of construct operationalization, data sources, survey instruments and coding procedures. All statistical tables referenced in the empirical sections are now presented in full, including descriptive statistics, correlation matrices, Confirmatory Factor Analysis (CFA) results, structural path coefficients with standard errors and instrumental variable diagnostics. Additionally, detailed survey items used to measure Probabilistic Uncertainty (QP), Cognitive Bias (CB) and Ethical Framing (EF) are provided in Appendix A, while the content-analysis coding protocol and interrater reliability statistics are reported in Appendix B. These additions ensure independent verification of the reported findings.

4.3. Econometric and behavioral probabilistic modeling strategy

The empirical validation of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) follows a two-tier modeling strategy integrating classical econometric estimation with probabilistic simulation. This dual design satisfies analytical emphasis on conceptual coherence and replicable statistical inference [2,5]. The econometric specification directly operationalizes the analytical structure presented in section 3.3 and empirically evaluates hypotheses H1–H5. To avoid redundancy, the theoretical rationale is not repeated in this section.

4.3.1. Structural Equation Model (SEM) specification: The first tier uses Structural Equation Modeling (SEM) to estimate interrelations among disclosure, assurance, cognitive and financial constructs defined in section 3.

The baseline equation system is:

$$ASC_i = \alpha0 + \alpha1ESGDQ_i + \alpha2APT_i + \alpha3ASS_i + \varepsilon_i \quad (6)$$

$$ASC^_i = ASC_i(1 - e^{-QP_i}) \quad (7)$$

$$CC_i = \gamma0 - \gamma1ASC^_i + \gamma2GI_i + \gamma3BI_i + \eta_i \quad (8)$$

$$ML_i = \delta0 + \delta1ASC^*_i + \delta2ESGDQ_i + \delta3GI_i + \delta4BI_i + \xi_i \quad (9)$$

Latent constructs—QP (probabilistic uncertainty), Cognitive Bias (CB) and Ethical Framing (EF)—are modeled as reflective indicators using confirmatory-factor loadings (≥ 0.70). Model identification is verified through $\chi^2/df<3.0$, $CFI>0.95$, and $RMSEA<0.06$, conforming standards for fit adequacy.

4.3.2. Probabilistic Simulation (QPS): The second tier applies a Probabilistic Simulation (QPS) to represent behavioral indeterminacy under ambiguity. Decision nodes managerial disclosure, auditor judgment and investor interpretation are simulated as simulated as interacting stochastic decision processes aligned with the twelve-construct architecture. The simulation captures how ethical framing and cognitive load shift the distribution of assurance credibility outcomes [8,13]. Simulation out-comes are calibrated to empirical SEM coefficients via monte carlo sampling (10,000 iterations), generating a Framework Consistency Index (FCI) analogous to R^2 but adjusted for uncertainty dispersion effects. Stochastic interaction effects dimension n=12 و"probabilistic amplitude interference"

4.3.3. Hypothesis testing procedure: The hypotheses developed in section 2.3 are tested sequentially:

- H1–H2: Regression of ASC on ESGDQ, APT, and ASS, moderated by QP and CB.
- H3: Interaction term ASC* × BI predicting Cost of Capital (CC).
- H4: Multi-group SEM comparing institutional coordination intensity (GI) across economies.
- H5: Behavioral probabilistic adjustment parameters tested for incremental explanatory power over classical models using likelihood-ratio tests.

Robustness is evaluated via clustered standard errors by country industry and bootstrapped confidence intervals (5,000 resamples).

4.3.4. Endogeneity and robustness controls: Potential reverse causality between assurance and financing efficiency is mitigated using Two Stage Least Squares (2SLS) with instrumental variables industry assurance density and prior year ESG index inclusion. Heteroskedasticity and cross-sectional dependence are controlled through White and Driscoll-Kraay corrections. Multicollinearity diagnostics (VIF<5) confirm model stability.

4.4. Comparative global benchmarking and interpretation

The benchmarking analysis contrasts empirical coefficients and descriptive indicators across Egypt, three emerging economies (India, Brazil, South Africa) and two advanced economies (United Kingdom, United States). The comparative evaluation addresses generalizability and contextual boundary conditions [16], as shown in Table 9.

4.4.1. Cross country patterns: Results reveal substantial heterogeneity in ESG disclosure quality and assurance credibility.

Table 9: *Comparative global benchmarking.*

Country group	ESGDQ (Mean 0–1)	ADI (Assurance Depth Index)	CU (Cognitive Uncertainty)	Cost of capital ↓ %	Market liquidity ↑ %
Egypt	0.58	0.46	0.62	– 5.8 %	4.10%
India	0.61	0.49	0.59	– 6.3 %	4.50%
Brazil	0.57	0.44	0.64	– 4.9 %	3.80%
South Africa	0.66	0.55	0.53	– 7.2 %	6.00%
United Kingdom	0.82	0.73	0.31	– 9.6 %	8.80%

United States	0.79	0.69	0.34	– 9.2 %	8.10%

4.4.2. Interpretation of differences:

- **Emerging economies (Egypt, India, Brazil, South Africa):** ESG assurance remains largely voluntary and fragmented; cognitive interference levels (QP>0.55) indicate higher judgmental ambiguity. Assurance premiums are modest because investors discount partially verified ESG metrics. Nonetheless, Egypt and South Africa show early regulatory traction through green finance frameworks.
- **Advanced economies (UK, US):** Regulatory mandates (FRC guidance, SEC proposals) and professional standard maturity (ISAE 3000, AICPA AT-C 320) yield deeper assurance scope and lower uncertainty (QP ≈ 0.32). Consequently, the elasticity of cost-of-capital reduction to ASC* is nearly –0.25 in advanced markets compared with –0.12 in emerging ones [42].
- **Global convergence dynamics:** Cross-sectional regressions show convergence of ESGDQ and ASC trajectories at ~3% annually post-2022, driven by ISSB adoption. Uncertainty dispersion (ΔQP) declines fastest in markets with explicit auditor-ethics training and integrated reporting systems [15].

4.4.3. Theoretical linkage: These findings validate the framework's prediction that assurance credibility is a probabilistic function of both cognitive and institutional parameters. Markets with stronger Governance Intensity (GI) exhibit smaller dispersion of QP and greater consistency of ASC–CC relationships, supporting the institutional coordination mechanism proposed in chapter 3. The benchmarking therefore provides external validity for the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) within a cross-context evaluation paradigm.

4.5. Methodological Rigor, Validity and Ethical Considerations

4.5.1. Reliability and validity: Internal consistency for multi-item constructs exceeds Cronbach's α=0.83; average variance extracted>0.55 ensures convergent validity. Discriminant validity is tested using Fornell Larcker criteria. To address cross-country comparability, all variables undergo measurement invariance tests (ΔCFI<0.01 across groups), confirming the model's structural equivalence.

4.5.2. Robustness and sensitivity analyses: Sensitivity analyses using alternative ESGDQ weightings (environmental=40%, social=30%, governance=30%) produce consistent coefficient signs. Re-estimating models with lagged ESGDQ confirms directionality of causality. Subsample robustness by sector indicates strongest framework effects in financial and energy industries domains with high data complexity and moral salience [10,14].

4.5.3. Ethical and transparency standards: Research procedures conform to the AAA research ethics guidelines (2024): full disclosure of data sources, anonymization of firm identifiers, and archiving of replication codes. Cross-country data usage complies with GDPR and local confidentiality regulations. The design avoids conflicts of interest by maintaining independence from assurance providers and regulatory institutions. In line with the "open science" movement, a deidentified dataset and model code will be made available upon publication.

5. Empirical Findings, Hypothesis Testing and Discussion

5.1. Overview of empirical analysis

The empirical investigation validates the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) developed in section 3 using the multi-country sample described earlier. Consistent with the emphasis on construct validity and cross-context generalization, the analysis evaluates whether higher disclosure quality and stronger assurance credibility jointly enhance capital-market efficiency, conditional on cognitive and institutional parameters [2]. The econometric architecture follows a sequential logic integrating Structural Equation Modeling (SEM), Two Stage Least Squares (2SLS) for endogeneity control and probabilistic simulation to represent behavioral uncertainty. All variables derive from the 2020–2024 panel of 300 listed entities across Egypt, India, Brazil, South Africa, the United Kingdom and the United States [5].

5.1.1. Empirical testing of hypotheses: This section reports the empirical results corresponding to hypotheses H1–H5 developed in section 2.3 and operationalized in sections 3 and 4. The results are presented sequentially, beginning with structural path estimates and followed by robustness and endogeneity tests.

5.2. Descriptive statistics and correlation patterns

Table 10 presents descriptive statistics and the correlation matrix.

Table 10: *Descriptive statistics and correlation matrix.*

Variable	Mean	SD	ESGDQ	ASC	ASC*	QP	CB	EF	GI	BI	CC	ML
ESGDQ	0.67	0.15	1									
ASC	0.54	0.2	0.61***	1								
ASC*	0.59	0.19	0.55***	0.74***	1							
QP	0.48	0.17	-0.42***	-0.46***	-0.51***	1						
CB	0.43	0.13	-0.25***	-0.31***	-0.33***	0.39***	1					
EF	0.52	0.14	0.36***	0.29***	0.33***	-0.28***	-0.21***	1				
GI	68.2	11.3	0.44***	0.39***	0.42***	-0.31***	-0.20***	0.23***	1			
BI	0.35	0.16	0.38***	0.41***	0.45***	-0.27***	-0.19**	0.19**	0.48***	1		
CC	0.084	0.018	-0.39***	-0.43***	-0.47***	0.29***	0.21***	-0.22***	-0.37***	-0.32***	1	
ML	0.63	0.2	0.46***	0.49***	0.52***	-0.34***	-0.18**	0.29***	0.35***	0.33***	-0.41***	1

5.2.1. Descriptive results: Table 10. reports summary statistics and correlations for the key constructs across all countries. Average ESG Disclosure Quality (ESGDQ) equals 0.67 (SD=0.15), confirming moderate sustainability reporting maturity. Assurance Credibility (ASC) averages 0.54 (SD=0.20), but the adjusted uncertainty adjusted credibility index (ASC*) rises to 0.59 when interference effects are considered. The mean Probabilistic (QP) uncertainty score of 0.48 suggests nontrivial behavioral uncertainty in auditor judgment [8,13]. Governance Intensity (GI) averages 68 out of 100, reflecting partial institutional enforcement in emerging markets. Mean Cost of Capital (CC) equals 8.4% and Market Liquidity (ML) averages 0.63 (turnover ratio × inverse price impact). Variance across nations is substantial: the UK and US show ESGDQ ≈ 0.80 and QP ≈ 0.32, while Egypt and Brazil record ESGDQ ≈ 0.58 and QP ≈ 0.62 [4,16]. The distributional diagnostics indicate normality for financial variables and mild right-skew for behavioral constructs (QP, CB). No extreme outliers exceed ±3 SD after winsorization at 1% tails. Variance inflation factors (VIF < 4) confirm the absence of multicollinearity.

Notes:

- Variables are standardized where appropriate; ***, **, * denote significance at 0.01, 0.05, 0.10 levels.
- All correlations two tailed and robust to heteroskedasticity.

5.2.2. Preliminary interpretation: The correlation matrix reveals patterns consistent with theoretical expectations. ESG Disclosure Quality (ESGDQ) correlates positively with Assurance Credibility (ASC) ($r=0.61$, $p<0.01$), sup-porting H1 at a descriptive level. Probabilistic (QP) uncertainty is negatively related to ASC ($r=-0.46$, $p<0.01$) and ASC* ($r=-0.51$, $p<0.01$), implying that greater cognitive interference reduces assurance credibility—an initial indication for H2.

The Cost of Capital (CC) correlates inversely with both ASC* (–0.47) and ESGDQ (–0.39), while Market Liquidity (ML) shows strong positive associations with the same variables (0.52 and 0.46, respectively). These patterns preliminarily support H3. Institutional variables (GI, BI) display consistent positive relations with ASC* and ML and negative relations with CC, suggesting contextual reinforcement predicted in H4 [28,42].

The cognitive constructs correlate moderately with each other (QP–CB r=0.39; QP–EF r=–0.28), consistent with cognitive behavioral theory [15]. Overall, the descriptive evidence indicates that probabilistic cognitive interference meaningfully covaries with assurance credibility and market performance motivating the formal hypothesis testing.

5.3. Model estimation results

5.3.1. Structural Equation Model (SEM) estimates: Table 11 presents the standardized coefficients and fit indices of the full structural model linking disclosure, assurance, cognition, and financial outcomes. The SEM model achieves satisfactory goodness-of-fit:

$\chi^2/df=2.41$, CFI=0.962, TLI=0.951, RMSEA=0.048, and SRMR=0.041, indicating strong construct reliability and convergence across the 300-firm sample [5].

The path from ESG Disclosure Quality (ESGDQ) to Assurance Credibility (ASC) is positive and significant ($\beta=0.318$, $t=5.27$, $p<0.01$), supporting the first-order prediction of signaling theory. Assurance Credibility (ASC) exhibits a strong negative effect on Cost of Capital (CC)

(β=–0.412, t=–6.08, p<0.01) and a positive impact on Market Liquidity (ML) (β=0.365, t=5.11, p<0.01).

Table 11: *Structural model estimation results (SEM & 2SLS).*

Path	Hypothesis	Coefficient (β)	t-stat	Sig.	Expected sign	Support
ESGDQ → ASC	H1	0.318	5.27	***	+	Supported
ESGDQ × QP → ASC	H2	–0.216	–3.94	***	–	Supported
ASC* → CC	H3a	–0.412	–6.08	***	–	Supported
ASC* → ML	H3b	0.365	5.11	***	+	Supported
GI × BI → CC	H4a	–0.289	–4.27	***	–	Supported
GI × BI → ML	H4b	0.244	3.68	**	+	Supported
QP → ASC* (Incremental)	H5	0.163	2.91	**	+	Supported (partial)
Path	Hypothesis	Coefficient (β)	t-stat	Sig.	Expected Sign	Support
ESGDQ → ASC	H1	0.318	5.27	***	+	Supported
ESGDQ × QP → ASC	H2	–0.216	–3.94	***	–	Supported
ASC* → CC	H3a	–0.412	–6.08	***	–	Supported
ASC* → ML	H3b	0.365	5.11	***	+	Supported
GI × BI → CC	H4a	–0.289	–4.27	***	–	Supported
GI × BI → ML	H4b	0.244	3.68	**	+	Supported
QP → ASC* (Incremental)	H5	0.163	2.91	**	+	Supported (partial)

Probabilistic uncertainty (QP) shows a significant negative moderating effect on the ESGDQ–ASC relationship (interaction β=–0.216, t=–3.94, p<0.01). This aligns with the behavioral decision logic that higher uncertainty diminishes assurance effectiveness [8,13].

Governance Intensity (GI) and Bank Integration (BI) both exert indirect positive effects on Market Liquidity (ML) and negative effects on CC, consistent with institutional interdependence mechanisms [16,42].

Model Fit: $\chi^2/df=2.41$; CFI=0.962; TLI=0.951; RMSEA=0.048; SRMR=0.041.
***p<0.01, **p<0.05, *p<0.10.

Although the overall model fit indices indicate strong structural coherence (CFI=0.962; RMSEA=0.048), effect sizes vary across subsamples and not all control paths reached conventional levels of statistical significance. In particular, the direct effect of ESGDQ on market liquidity in two emerging-market subsamples was statistically weaker ($p < 0.10$), and the mediation strength of ASC* varied meaningfully by governance intensity.

These variations confirm that the model is context sensitive rather than uniformly deterministic.

5.3.2. Two Stage Least Squares (2SLS) verification: To address potential endogeneity between assurance credibility and financial outcomes, a 2SLS model uses lagged ESGDQ and industry average assurance density as instruments [47].

Results confirm SEM findings:

- ASC* remains negatively associated with CC (β=–0.389, p<0.01) and positively with ML (β=0.347, p<0.01).

- Instrumental relevance is verified (F-stat=21.6, p<0.01; Hansen J-test p=0.28).

These diagnostics indicate no over identification or weak instrument bias.

Overall, the combined SEM–2SLS analysis provides strong empirical confirmation of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)'s causal logic: credible ESG dis-closure and assurance reduce information asymmetry and financing costs while enhancing liquidity [2,10]. Table 12 presents Instrumental Variable Diagnostics (2SLS).

Table 12: *Instrumental variable diagnostics (2SLS).*

Test	Statistic	p-value	Interpretation
First-stage F-statistic	21.6	<0.01	Strong instrument relevance
Hansen J-test	1.87	0.28	No overidentification bias
Endogeneity test (Durbin-Wu-Hausman)	3.12	0.07	Mild endogeneity controlled

5.3.3. Behavioral Probabilistic Simulation (QPS) adjustments: The Probabilistic Simulation (QPS) quantifies the incremental explanatory power of cognitive interference relative to classical models as shown in Table 13 [8,13].

- Mean Framework Consistency Index (FCI)= 0.714, improving baseline R^2 by 11%.
- The simulated cross-system dependence coefficient (ρ)=0.38, indicating moderate interdependence among assurance agents and market participants.

As shown in Table 11, the uncertainty-adjusted Assurance Credibility (ASC*) exhibits the highest financial impact in advanced economies (elasticity –0.27 with CC), while Egypt and Brazil display reduced magnitudes (–0.12 to –0.15) due to higher QP levels (≥ 0.55).

Table 13: *Behavioral probabilistic cognitive adjustments and country comparisons (2020–2024).*

Country / Group	Mean QP	ASC* Mean	ΔCC (Elasticity)	ΔML (Elasticity)	QCCI
Egypt	0.61	0.52	–0.12	0.1	0.64
India	0.58	0.54	–0.14	0.11	0.66
Brazil	0.63	0.5	–0.15	0.09	0.63
South Africa	0.53	0.57	–0.18	0.14	0.7
United Kingdom	0.31	0.72	–0.26	0.22	0.79
United States	0.34	0.69	–0.27	0.21	0.78

5.3.4. Robustness and sensitivity analyses: To address concerns regarding potential overfitting and sample homogeneity, multiple robustness checks were conducted:

- Re-estimation using alternative ESGDQ weighting schemes.
- Exclusion of advanced economies to test emerging-market sensitivity.
- Lagged model specifications to mitigate simultaneity bias.
- Bootstrapped confidence intervals (5,000 resamples).

Results remained directionally consistent, although effect magnitudes were attenuated in lower-governance environments.

5.4. Testing research hypotheses (H1–H5)

Consistent with reporting standards, this section isolates the empirical evaluation of each hypothesis, summarizing significance, direction and theoretical interpretation as shown in Table 14.

- **H1–ESG Disclosure Quality (ESGDQ) enhances assurance credibility:** As predicted, ESGDQ exerts a strong positive influence on ASC (β=0.318, $p<0.01$). This finding aligns with signaling theory and previous assurance literature emphasizing disclosure transparency as a trust signal. H1 is fully supported [2].
- **H2–Cognitive interference moderates the disclosure assurance link:** The interaction term ESGDQ × QP is negative and significant (β=–0.216, $p<0.01$), confirming that high uncertainty weakens the link between disclosure and assurance quality. The result substantiates the behavioral-assurance argument advanced by Kadous et al. [14] and Loewenstein et al. [15]. H2 is supported.
- **H3–Assurance credibility improves financial efficiency:** Uncertainty-adjusted Assurance Credibility (ASC*) shows significant effects on both financial metrics:
  - CC (β=–0.412, $p<0.01$) and
  - ML (β=0.365, $p<0.01$).

  This confirms the mediating role of credible assurance in reducing financing costs and improving liquidity [5,10]. H3 is fully supported.
- **H4–Institutional interdependence reinforces assurance benefits:** The interaction of Governance Intensity (GI) and Bank Integration (BI) yields significant moderating effects on CC and ML ($p<0.05$). Markets with higher regulatory coherence experience stronger assurance finance linkages [32,42]. H4 is supported.
- **H5–Behavioral probabilistic parameters add explanatory power:** The incremental inclusion of QP and CB variables increases model R^2 from 0.49 to 0.56, and the FCI improves by 11%. This demonstrates measurable behavioral variance beyond classical audit-risk constructs, validating the behavioral–probabilistic extension [8,12]. H5 is partially supported due to heterogeneity across countries.

Table 14: *Summary of hypothesis testing results.*

Hypothesis	Statement	Expected sign	Empirical sign	t-stat	p-value	Support level	Interpretation
H1	ESGDQ → ASC	+	+	5.27	<0.01	Supported	Higher disclosure quality strengthens assurance credibility
H2	ESGDQ × QP → ASC	–	–	–3.94	<0.01	Supported	Cognitive uncertainty weakens assurance effect
H3	ASC* → CC, ML	–/+	–/+	6.08/5.11	<0.01	Supported	Assurance credibility

							improves financial efficiency Institutional entanglement amplifies assurance outcomes Behavioral–probabilistic cognition adds behavioral explanatory power
H4	GI × BI → CC, ML QP, CB	–/+	–/+	– 4.27/3.68	<0.05	Supported	
H5	incremental	+	+	2.91	<0.05	Partially supported	

5.4.1. Overall interpretation: The hypothesis tests collectively validate the core postulates of Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF). Evidence indicates that ESG assurance operates not merely as a procedural verification but as a probabilistic cognitive system. Disclosure quality, cognitive interference, and institutional governance interact multiplicatively to determine assurance credibility and its financial impact.

Effect sizes are economically material: a one-standard-deviation increase in ASC* corresponds to a 0.42% decrease in cost of capital and a 0.37% increase in liquidity, underscoring the financial relevance of assurance quality in both emerging and advanced contexts. These findings bridge the gap between audit theory, behavioral decision science, and sustainability reporting, consistent with empirical frameworks linking accounting information to capital-market consequences [4].

5.5. Comparative findings across institutional contexts

5.5.1. Cross country differences: Table 3 (section 5.3) revealed notable heterogeneity in both cognitive uncertainty and assurance performance. Cross country comparisons show a structural divergence consistent with institutional theory and behavioral asymmetry [7,16].

In Egypt, average ESG disclosure (ESGDQ=0.58) and assurance credibility (ASC*=0.52) are below the global mean, while probabilistic uncertainty (QP = 0.61) remains the highest among the sample. Similar conditions are found in Brazil (QP=0.63). These findings highlight the persistence of informational opacity and limited standardization in emerging [4].

In contrast, the United Kingdom and the United States exhibit significantly higher ESGDQ (≥ 0.78) and lower QP (≈0.32), reflecting robust assurance ecosystems and auditor training structures [18,63]. The elasticity of financial outcomes to ASC* is nearly double in advanced economies (–0.26 for cost of capital, +0.22 for liquidity) relative to emerging peers (–0.13, +0.10).

These results confirm that regulatory coordination—coherent standards between financial regulators, banks and audit authorities—produces higher assurance credibility and market rewards [42]. Egypt's introduction of sustainable-finance guidelines and green-bond frameworks since 2022 signals incremental alignment with such convergence.

5.5.2. Institutional and behavioral path dependence: Comparative path analysis indicates that emerging economies demonstrate greater sensitivity of assurance credibility to cognitive uncertainty (βQP×ASC=–0.28) than advanced markets (β =–0.11). This supports the behavioral-friction hypothesis: in systems with weaker professional norms, auditors' probabilistic cognition influences assurance reliability more strongly [14,15]. Institutional Governance Intensity (GI) explains roughly 32% of the variance in ASC* across countries. Regression decomposition shows that half of this effect operates through Banking Integration (BI) channels particularly green lending policies linking credit risk to verified ESG performance. This reinforces the systemic view of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) as both a behavioral and institutional architecture.

5.5.3. Emerging advanced convergence: Trend analysis from 2020–2024 demonstrates partial convergence: ESGDQ increased by 15% and ASC* by 12% across emerging economies, narrowing the assurance credibility gap by one-third. Nevertheless, convergence in cognitive efficiency (decline in QP) remains slower only 6% over four years signaling persistent human judgment variability. These mixed trajectories suggest that technological alignment precedes cognitive harmonization in ESG assurance development [10].

5.6. Robustness, sensitivity and additional analyses

5.6.1. Robustness tests: To ensure the stability of reported findings, three robustness procedures were performed consistent with standards for empirical replication. Alternative variable specifications: ESGDQ weights (E/S/G=0.4/0.3/0.3) were rebalanced to 0.33 each; all signs and significance levels remained consistent:

- **Lagged estimation:** Regressing CC and ML on lagged ASC* (t–1) preserved coefficient magnitudes (β=–0.39 and 0.35, respectively).
- **Subsample analysis:** Re-estimation for non-financial sectors (n=180) yielded similar results, indicating no industry concentration bias.

Bayesian SEM confirmed posterior convergence with 95% credibility intervals overlapping OLS estimates, suggesting robustness to distributional assumptions.

5.6.2. Endogeneity and multicollinearity diagnostics: Hausman tests indicate exogeneity of ESGDQ (p=0.42), while instrument validity (Hansen J-test p=0.28) confirms no over-identification. Variance inflation factors remain<4.0 for all variables. Serial correlation tests (Durbin–Watson=1.96) confirm independence of residuals. These diagnostics meet econometric rigor standards for model validity [5].

5.6.3. Sensitivity and behavioral threshold effects: Quantile regressions across ESGDQ percentiles (25th–75th) show asymmetric impacts: the positive ESGDQ → ASC relationship strengthens at higher disclosure levels (β75th=0.42 vs. β25th=0.29). However, at extreme QP > 0.65, the marginal assurance effect turns insignificant, confirming a behavioral saturation threshold consistent with contextual decision predictions [13]. Monte carlo simulations (10,000 replications) yield stable means for ASC*, CC and ML, validating the probabilistic consistency of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) across 95% confidence intervals.

5.6.4. Validation of behavioral probabilistic parameters: Entropy analysis reveals an average uncertainty dispersion (H) of 0.67 in emerging markets and 0.49 in advanced economies. The decline in dispersion correlates with institutional maturity, providing

empirical evidence that cognitive coherence is a measurable determinant of assurance performance. These results reinforce H5 and confirm that behavioral variance possesses explanatory depth beyond classical metrics.

5.7. Discussion and theoretical interpretation

5.7.1. Integrating empirical and theoretical insights: The collective findings support all primary hypotheses (H1–H4) and partially validate H5, affirming that ESG assurance is both an informational and cognitive process. The results extend traditional assurance literature by embedding behavioral probabilistic decision modeling as a representation of auditor judgment into the structural model of sustainability verification [8,15]. The data demonstrate that Assurance Credibility (ASC*) mediates the ESGDQ financial performance relationship, bridging disclosure theory with behavioral auditing models. The emergence of statistically significant cognitive parameters (QP, CB, EF) substantiates the role of interference, uncertainty and ethical framing in shaping assurance reliability. This provides an empirical foundation for future behavioral quantitative integrations.

5.7.2. Theoretical contribution: This chapter contributes to the audit–information–market nexus by introducing three novelties:

- **Behavioral probabilistic modeling:** Extends assurance theory from deterministic judgment to probabilistic cognition, capturing decision interference effects.
- **Institutional interdependence logic:** Demonstrates that governance intensity and financial integration jointly moderate assurance outcomes, validating a coordinated governance paradigm.
- **Behavioral financial mediation:** Establishes assurance credibility as a mediator linking ethical cognition to capital market efficiency.

These insights advance the behavioral foundations of auditing research and align with emphasis on measurable, theory consistent empirical generalization.

5.7.3. Policy and practice implications: Empirical validation of Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) provides a credible foundation for a proposed ESG assurance standard (Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)) suitable for emerging markets. Policymakers such as Egypt's financial regulatory authority and central Bank can leverage the identified behavioral thresholds to design targeted auditor training, AI assurance protocols and integrated ESG reporting mandates.

Cross-national convergence in assurance credibility suggests the possibility of a global ESG assurance accord, harmonizing ISSB, IAASB and national standards enhancing transparency and investor confidence globally [4,16].

5.7.4. Implementation considerations and practical constraints:

- Survey based measures require institutional access
- Cross country comparability challenges
- Assurance depth heterogeneity
- Training costs for behavioral integration
- Need for pilot studies before policy translation

6. Policy Implications and the Proposed Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)

6.1. Introduction and policy context

The empirical evidence presented in chapter 5 reveals that Assurance Credibility (ASC*) operates as a behavioral probabilistic mechanism linking disclosure quality to capital market efficiency. This finding extends beyond theoretical validation: it provides a normative foundation for policy intervention in sustainability assurance, governance and financial supervision. Consistent with emphasis on decision usefulness and institutional accountability., translating the Behavioral Probabilistic ESG Assurance Framework (BPEAF). Into a regulatory standard becomes essential for ensuring comparability and investor protection.

Over the past five years, international standard-setters including the International Sustainability Standards Board (ISSB), International Auditing and Assurance Standards Board (IAASB) and International Federation of Accountants (IFAC) have advanced parallel initiatives to formalize ESG-assurance requirements [4,18]. However, empirical cross-country findings demonstrate that behavioral heterogeneity and institutional fragmentation persist, especially across emerging economies such as Egypt, India and Brazil [16,42]. Without integrating cognitive-behavioral dimensions into regulatory design, assurance credibility remains context sensitive rather than systemic.

The ESG assurance standard (Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)) proposed here therefore represents an applied policy translation of Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF). It aims to institutionalize robust assurance governance within both national and global ESG reporting architectures. By embedding uncertainty indicators, ethical-framing requirements and bank-level coordination indices, Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) operationalizes the concept of "assurance coherence" ensuring that informational and behavioral components of audit quality inter-act transparently.

6.2. Implications for regulators, auditors and banks

6.2.1. For regulators and policy makers: Regulatory authorities such as Egypt's Financial Regulatory Authority (FRA), the Central Bank of Egypt (CBE) and stock exchange oversight bodies should integrate QESG aligned indicators into their corporate governance and listing frameworks. Empirical findings indicate that Governance Intensity (GI) and Banking Integration (BI) significantly moderate the financial benefits of assurance credibility [57]. Regulators can institutionalize these effects by:

- Mandating ESG assurance under Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) for listed firms exceeding specified market capitalization thresholds;
- Embedding cognitive risk disclosures in auditors' reports, analogous to "key audit matters," capturing QP (uncertainty index) and CB (cognitive-bias) metrics;
- Aligning national ESG governance codes with ISSB S1/S2 disclosure principles and ISAE 3000 (Revised) assurance criteria;
- Creating an assurance transparency repository, enabling investors to benchmark assurance credibility across firms and sectors.

Such measures address the asymmetry between informational and behavioral assurance risks, transforming probabilistic trust into institutionalized confidence [2,3,5].

6.2.2. For auditors and assurance firms: Auditors must expand competence beyond procedural ESG verification toward behavioral assurance analytics. The Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) results demonstrate that cognitive interference reduces assurance reliability, especially in emerging markets. Therefore, Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) recommends:

- Continuous professional education in cognitive decision sciences and behavioral ethics.
- Integration of AI based probabilistic evaluation tools capable of modeling uncertainty patterns in auditor judgment.
- Use of assurance dashboards to quantify Assurance Credibility (ASC*) indices in real time.
- Disclosure of assurance uncertainty maps in ESG audit reports, supporting investor interpretation.

These actions align with behavioral-audit research trajectory [14,15,42,54,64] and strengthen the link between judgment quality and market outcomes.

6.2.3. For banks and capital market intermediaries: Banks emerged in chapter 5 as catalytic agents for ESG assurance adoption. Through their credit and investment decisions, financial institutions internalize assurance credibility as a proxy for ESG risk. To operationalize this dynamic, Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) encourages banks to:

- Integrate Assurance Credibility Scores (ACS) into credit risk models.
- Link sustainable-finance incentives to verified QESG assured disclosures.
- Collaborate with regulators to create green credit registries that reward high assurance firms.
- Report aggregated ESG assurance data to supervisory authorities, promoting systemic transparency [42].

In the Egyptian context, such coordination complements the CBE's green finance guidelines (2023) and positions banks as key intermediaries in enforcing assurance integrity (Table 15).

Table 15: *Summarizes of policy and regulatory implications.*

Stakeholder	Policy action / instrument	Expected outcome	Reference alignment
Regulators (FRA, CBE, EGX)	Mandate Behavioral–Probabilistic ESG Disclosure and Assurance Framework (BPEAF) assurance; establish assurance transparency repository	Enhanced disclosure reliability; lower cognitive uncertainty	IFAC [4]; IAASB [18]; OECD [32]
Auditors & firms	Adopt behavioral–probabilistic tools; disclose QP & CB metrics	Improved assurance credibility (ASC*); behavioral accountability	Davidson et al. [14];

Banks & investors	Embed ASC* in credit models; tie financing to QESG scores	ESG risk pricing efficiency; liquidity improvement	BIS [42]
Academia & professional bodies	Develop behavioral-audit training; certify QESG specialists	Knowledge diffusion; standardized competencies	Loewenstein et al. [15]
International agencies (ISSB, IFAC)	Coordinate cross-standard adoption; monitor convergence metrics	Global assurance comparability; reduced reporting entropy	IFAC [4]; OECD [16]

6.3. The proposed Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) assurance standard

6.3.1. Concept and objectives: The proposed ESG assurance standard (Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) is the normative translation of the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF). Its design responds to empirical evidence that Assurance Credibility (ASC*) is jointly determined by informational transparency, behavioral cognition, and institutional coherence. The standard aims to codify assurance coherence the alignment between disclosure veracity, auditor judgment integrity and market trust [13,14].

Drawing inspiration from ISAE 3000 (revised) and the ISSB S1/S2 disclosure baseline, Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) introduces behavioral probabilistic extensions absent from existing standards. It redefines assurance quality as a composite function:
AQ=f(ESGDQ,ASC,QP,CB,EF,GI,BI) AQ=f(ESGDQ, ASC, QP, CB, EF, GI, BI) AQ=f(ESGDQ, ASC,QP,CB,EF,GI,BI)

where AQ represents overall assurance quality, integrating both deterministic (reporting) and stochastic (cognitive) variables.

6.3.2. Core components and structure: Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) comprises five interconnected pillars, mirroring the logic of applied theory orientation:

Disclosure integrity and data traceability:

- Mandates machine-verifiable ESG metrics consistent with ISSB S2 climate and S1 general purpose requirements.
- Requires dual-layer data validation: automated Artificial Intelligence (AI) and professional (auditor).

Cognitive assurance and ethical framing:

- Introduces Cognitive Interference Disclosure (CID) sections in audit reports summarizing uncertainty and Ethical Framing (EF) indicators.
- Requires firms to disclose assurance uncertainty ranges analogous to confidence intervals [13].

Institutional coordination and banking alignment:

- Establishes reporting links between external auditors, supervisory regulators and bank risk teams.
- Promotes use of Assurance Credibility Scores (ACS) in both capital adequacy and ESG risk assessments [42,65].

Assurance Transparency Repository (ATR):

- Centralized digital registry hosted by national regulators (e.g., FRA) to publish QESG-compliant assurance results.
- Enhances market comparability and deters "green-washing" by making ASC*, QP and CB data public [32].

Continuous learning and cognitive audit training:

- Requires auditors to complete Behavioral ESG Certification emphasizing probabilistic reasoning, ethical salience and AI analytics [14].

These pillars institutionalize what empirical analysis in chapter 5 demonstrated: that sustainable assurance credibility depends equally on human judgment quality and institutional design [2,5].

6.3.3. Alignment with global standards: Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) is intentionally complementary, not substitutive, to prevailing frameworks as shown in Table 16 [66].

Table 16: *Alignment with global standards.*

Domain	Existing Standard	Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) integration
Sustainability reporting	ISSB S1 / S2	Adds behavioral-assurance parameters to disclosure reliability
Assurance practice	ISAE 3000 (revised)	Extends scope to include behavioral–probabilistic cognitive metrics
Audit ethics	IESBA code of ethics	Embeds Ethical-Framing quantification (EF index)
Regulatory governance	Basel III / BIS green finance principles	Links assurance credibility to ESG risk weighting

Collectively, these alignments ensure global interoperability while allowing Egypt and other emerging markets to pioneer behavioral assurance integration ahead of formal international adoption.

The proposed framework complements, rather than replaces, existing standard-setting efforts such as the IAASB's ISSA 5000. While ISSA 5000 focuses on procedural rigor, evidence gathering, and assurance scope harmonization, the present framework emphasizes behavioral transparency and probabilistic uncertainty disclosure. No attempt is made to replicate or override ISSA 5000 provisions.

7. Conclusion and Future Research Directions

7.1. Summary of key findings

This study developed, empirically validated and policy translated the Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) as a next generation model for understanding and improving ESG assurance credibility. Using a multi country dataset covering Egypt, three emerging economies and two advanced markets, the research demonstrated that Assurance Credibility (ASC*) functions as a probabilistic bridge linking disclosure transparency to market efficiency.

Five hypotheses (H1–H5) were tested through Structural Equation Modeling (SEM), Two Stage Least Squares (2SLS) and Probabilistic Simulation (QPS). Results revealed:

- ESG disclosure quality (ESGDQ) significantly enhances assurance credibility (H1).
- Cognitive interference moderates this effect, reducing assurance reliability in high-uncertainty environments (H2);
- Uncertainty adjusted Assurance Credibility (ASC*) decreases cost of capital and increases market liquidity (H3);
- Institutional coordination/interdependence joint strength of Governance Intensity (GI) and Banking Integration (BI) amplifies assurance benefits (H4); and
- Behavioral probabilistic parameters add incremental explanatory power beyond classical audit risk models (H5).

These results collectively validate the premise that assurance credibility depends not only on procedural compliance but also on behavioral coherence and institutional alignment. They also confirm the economic materiality of assurance quality, as demonstrated by measurable reductions in financing costs and improvements in market liquidity across jurisdictions [2,5,12].

7.2. Theoretical and practical contributions

Theoretically, this research advances behavioral-accounting literature by connecting probabilistic decision theory with auditing assurance theory [8,13]. Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) reconceptualizes assurance as a dynamic probability field in which auditor cognition, ethical framing and institutional parameters interact. This probabilistic lens overcomes limitations of deterministic audit risk models by capturing nonlinear human judgment a persistent empirical gap identified in recent audit studies [14,15].

Practically, the findings provide regulators, auditors and banks with quantifiable metrics for improving sustainability governance. The proposed ESG assurance standard (Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)) institutionalizes these insights through five pillars: disclosure integrity, cognitive assurance, institutional coordination, transparency repositories and continuous learning. By embedding cognitive and probabilistic parameters in assurance practice, Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF) bridges the and informational dimensions of ESG verification [4,18].

For emerging markets such as Egypt, the framework operationalizes evidence-based regulation by linking assurance credibility to market outcomes. It provides actionable mechanisms for aligning national governance reform with global benchmarks [16].

7.3. Limitations and future research directions

Despite its robustness, the study acknowledges several limitations that open avenues for future research. First, measurement of cognitive variables (QP, CB, EF) relied on proxy indicators derived from assurance narratives and survey responses. Future studies could employ experimental auditing designs or AI based text analytics to directly capture cognitive bias intensity and ethical framing across auditors.

Second, the sample was limited to six countries and a five-year period (2020–2024). Expanding cross-sectional and longitudinal coverage especially including Asian and European Union markets would enhance external validity and enable institutional path analysis of assurance convergence.

Third, while the Probabilistic Simulation (QPS) successfully modeled uncertainty, it remains computationally demanding. Future research may explore hybrid AI based approaches to optimize assurance probability modeling and test real-time predictive capabilities.

Fourth, further investigation is warranted into policy diffusion mechanisms how regulatory adoption of Behavioral Probabilistic ESG Disclosure and Assurance Framework (BPEAF)-100 or similar frameworks influences firm behavior, auditor incentives and investor reactions. This calls for multi-level empirical studies integrating accounting, economics and regulatory governance perspectives [42,67].

Finally, the ethical dimension of probabilistic assurance invites philosophical and professional inquiry: how should auditors communicate uncertainty to stakeholders without eroding trust? This question opens a rich future agenda for, ethical and communication-accounting scholars within the community.

8. Conflict of Interest Statement

The author declares that there is no conflict of interest regarding the publication of this paper. The author has no financial, personal or professional relationships that could have appeared to influence the work reported in this study.

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Appendix

Appendix A

Appendix A. Survey Instrument for Cognitive Constructs

Survey administration overview

The survey instrument was administered between March and July 2024 to senior auditors and ESG-assurance specialists involved in sustainability engagements across the sampled jurisdictions. A total of 124 questionnaires were distributed electronically; 87 valid responses were received (response rate=70.2%). Respondents had a minimum of five years' professional experience in audit or assurance practice.
All items were measured using a five-point Likert scale
(1=Strongly disagree; 5=Strongly agree).

Section A: Probabilistic Uncertainty (QP)

This construct captures perceived ambiguity, interpretive dispersion, and judgmental uncertainty in ESG assurance contexts.
QP1. Sustainability disclosures often contain forward-looking estimates that are difficult to verify objectively.
QP2. Evaluating ESG metrics involves substantial interpretive ambiguity.
QP3. Determining materiality thresholds in sustainability assurance requires subjective judgment.
QP4. Conflicting ESG evidence frequently complicates assurance conclusions.
QP5. ESG related risks are harder to quantify compared to traditional financial risks.
QP6. Assurance judgments in sustainability reporting are highly context-dependent.
Cronbach's α=0.86
Composite Reliability (CR)=0.88
Average Variance Extracted (AVE)=0.58

Section B: Cognitive Bias (CB) Intensity

This construct measures heuristic reliance and potential bias patterns in ESG-related audit judgments.
CB1. Prior client reputation influences my evaluation of ESG disclosures.
CB2. I tend to rely on previously used benchmarks when assessing sustainability metrics.
CB3. Initial impressions of ESG reporting quality affect subsequent evidence evaluation.
CB4. Time pressure increases reliance on simplified decision heuristics in ESG assurance.
CB5. I sometimes give greater weight to information confirming prior expectations.
Cronbach's α=0.83
Composite Reliability (CR)=0.85
AVE=0.56

Section C: Ethical Framing (EF)

This construct captures the influence of moral salience and professional ethics activation on assurance judgments.
EF1. Sustainability related issues heighten my sense of professional responsibility.

EF2. Ethical considerations influence my materiality assessments in ESG engagements.
EF3. ESG disclosures activate stronger skepticism compared to routine financial disclosures.
Cronbach's α=0.87
Composite Reliability (CR)=0.89
AVE=0.60

Construct validation: Confirmatory Factor Analysis (CFA) confirmed satisfactory convergent and discriminant validity. All standardized factor loadings exceeded 0.70 and were significant at $p<0.01$. Measurement invariance tests across country groups showed $\Delta CFI<0.01$, indicating structural equivalence across jurisdictions.

Appendix B

Appendix B. Content Analysis Coding Protocol

B1. Objective

The content analysis aimed to operationalize Assurance Scope (ASS), Assurance Credibility (ASC depth component), and Ethical Framing (EF textual dimension) from sustainability assurance reports issued under ISAE 3000 (Revised) and equivalent national standards.

B2. Coding procedure

- All ESG assurance statements (2020–2024) were collected from annual reports and standalone sustainability reports.
- Reports were anonymized and assigned random identification codes.
- Two independent coders with professional audit backgrounds were trained using a standardized coding manual.
- Coding was conducted in three stages:
  Stage 1: Identification of assurance provider type and scope.
  Stage 2: Evaluation of disclosure–assurance alignment.
  Stage 3: Linguistic analysis of ethical salience and skepticism language.

B3. Coding dimensions

Assurance Scope (ASS)

- 1=Limited assurance
- 2=Reasonable assurance

Assurance Credibility Depth (ASC-Depth)
Scored on a 3-point ordinal scale:

- 1=Boilerplate language, minimal procedure description
- 2=Moderate procedural detail and risk explanation
- 3=Detailed methodological transparency and explicit evidence discussion

Ethical Framing linguistic score (EF-text)
Measured using structured keyword frequency and contextual interpretation:
Indicators included:

- References to professional skepticism
- Explicit acknowledgment of ESG uncertainty

- Discussion of stakeholder impact
- Emphasis on independence and ethical responsibility
- Scores normalized on a 0–1 scale.

B4. Inter-rater reliability

Inter-rater reliability was assessed using Cohen's Kappa:

- Assurance Scope (ASS) κ=0.91
- Assurance Credibility depth (ASC-depth) κ=0.84
- Ethical Framing linguistic coding (EF-text) κ=0.82

All coefficients exceed the 0.80 benchmark for strong agreement. Discrepancies were resolved through consensus meetings. Final coded data were used in the SEM estimation.

B5. Replicability

The full coding manual, keyword dictionary and scoring rubric are archived and available upon rea-sonable request to ensure methodological transparency and replicability.